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Annual Summary Report

THE FREQUENCY-SEPARATED DISPLAY PRINCIPLE: PHASE II

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INTRODUCTION

This is an annual report summarizing the work performed on Contract N0014-67-A-0305-0014 during the period 1 April 1969 through 31 October 1970. The report includes: 1) a brief review of the frequency-separated display problem, 2) a summary of the work accomplished during Phase I, 3) work accomplished during Phase II, 4) research plans for Phase III, and 5) personnel involved in the research. Two Technical Reports have been issued under this contract: ONR-70-1, June 1970, and ONR-70-2, October 1970.

THE DISPLAY MOTION RELATIONSHIP PROBLEM

The Problem

Over the years the most controversial issue in flight display design has been the question of what should move, the airplane or the outside world. The issue manifests itself in many separate issues involving all dimensions of aircraft control including attitude, altitude, heading, and speed and their derivatives. The issues are not simple: although the bulk of the experimental evidence favors having the aircraft move, most modern flight displays have inside-out presentations with moving scales, moving horizons, and fly-to moving indices.

It must be concluded that the basic moving-horizon type of attitude presentation, for example, is so well established and its interpretation so over-learned by pilots that its basic movement relationships will never be changed. Still the fact that pilots continue to make critical control reversals using the moving-horizon display cannot be ignored. We must try to find ways of improving the presentation of attitude information without disrupting pilots' present habit patterns and preferences.

If one looks carefully at the problem of attitude control reversals, it becomes apparent that the reversal phenomenon is usually associated with a sudden change in attitude such as a dropped wing caused by a gust of turbulent air or the rapid changes in attitude required in following a noisy steering dot in an air-to-air attack. In slow routine maneuvers pilots have little trouble with the moving horizon. The problem seems to be associated almost exclusively with the high frequency components of the display indications. In other words, it appears that the critical consideration is that the elements of a display that respond immediately to the pilot's control inputs move in the expected direction. It appears that the direction of movement of the more slowly responding display indications is far less critical.

The Principle of Frequency Separation

These observations lead to the notion of the frequency separation principle of display which has been propagated by various people but never explicitly tested in any formal experimental program. The best known example of the frequency separation principle is the so-called kinalog display system proposed by Lawrence Fogel in 1959.

Fogel demonstrated an attitude-director display system in which the initial response of the attitude presentation was outside-in. For example, if the pilot moved his stick to the right to initiate a right turn, the aircraft symbol initially rotated clockwise. As the aircraft established its right turn, the horizon line on the display and the aircraft symbol both gradually rotated counterclockwise so that in a steady-state turn the aircraft's bank angle was indicated by a tilted horizon line. Upon rolling out of the turn, once again the first indication of the display was the counterclockwise rotation of the aircraft symbol followed more slowly by the clockwise rotation of the horizon line and aircraft symbol back to level.

While this display system was never tested experimentally, the simple laboratory demonstration of its operation was extremely easy to interpret and showed enough promise to warrant further investigation.

Institute of Aviation Studies

In December of 1968 the Institute of Aviation submitted a proposal to the Office of Naval Research to study these motion relationship problems. Upon receipt of a contract in April of 1969, preliminary studies commenced at the Institute, and a subcontract was let to Hughes Aircraft Company to develop a versatile CRT display apparatus which could be used to study various aspects of the problem. A description of the make-up of this apparatus and its capabilities is included in the section, "Summary of Phase I."

SUMMARY OF PHASE I PROGRESS

The effective dates under which the first phase of the program was in progress were 1 April 1969 to 31 March 1970. During that period three major areas of endeavor were undertaken: development of experimental apparatus under a subcontract with Hughes Aircraft Company, installation of equipment in the Beechcraft C-45H flight research vehicle, and planning the formal experiments.

Experimental Apparatus

A block diagram of the experimental apparatus is depicted in Figure 1. Flight path commands are generated in two different ways. In one way a flight command generator provides digital storage for rapidly replaceable, programmable vertical and horizontal commands. The two task generators are rotary stepping switches driven by an electronic timer. The time increments provided by the timer can be varied to change the time between steps. Movable tabs on the drum of the switch allow various sequences of horizontal or vertical steering commands to be programmed. The outputs from the switches go through a digital-to-analog conversion to provide predetermined analog outputs of variable voltage which can be used to drive the steering command index on the display. A possible range of from 16 positive

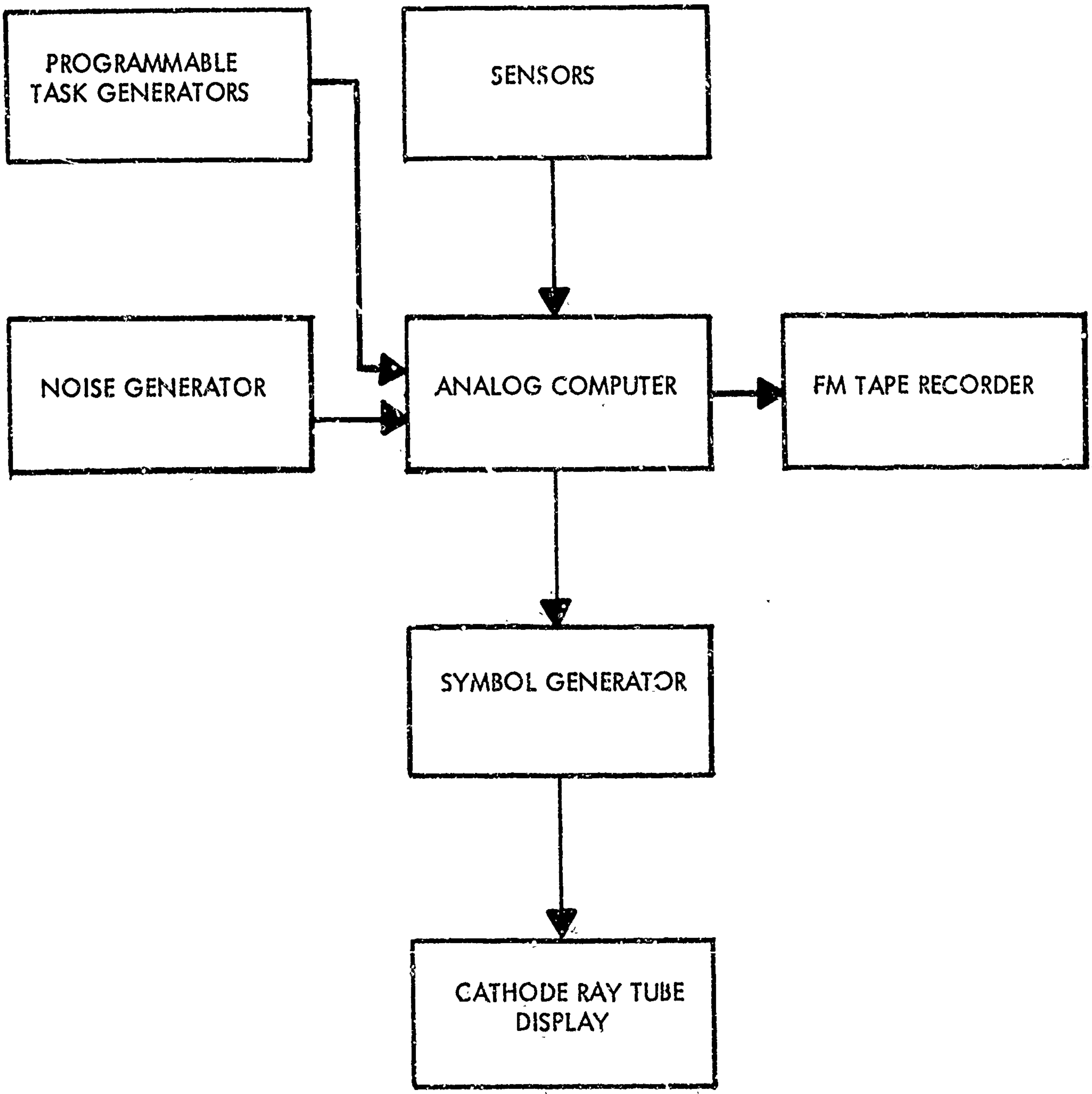

FIGURE 1
EXPERIMENTAL APPARATUS
BLOCK DIAGRAM

to 16 negative command values is available at each step in the exercise. There are 60 steps which occur at varying intervals averaging five seconds. The output of the digital storage is converted to DC analog voltage steps corresponding to commands on the vertical and horizontal axes. This discrete task provides for discrimination between displays with respect to reversal errors.

The second way in which flight path commands are generated is with the use of a Gaussian noise generator. This allows the subject to follow continuously varying commands.

Error detection circuitry provides instantaneous values of vertical and horizontal error to an external recorder which also contains a time reference channel and a record of flight commands and aircraft responses.

A symbol generator provides the basic display elements which are driven from the analog signals for the various modes. While in flight, the experimenter can change the mode by simply changing pre-patched panels on the symbol generator.

The experimental apparatus utilizes an electronically-generated display approach. This method of display was decided upon because of its versatility of display format, reliability of operation, similarity to advanced systems, and mechanical simplicity.

The display is a Tektronix 503 oscilloscope in which the CRT has been removed and mounted in the instrument panel. The oscilloscope approach was decided upon because of its availability, performance and rapidity of beam deflection if needed.

The display is driven by an eight-channel symbol generator mounted in an equipment rack which replaces two of the seats in the cabin of the aircraft. Line driven outputs are provided to insure good signal propagation down the coaxial cables to the display. The eight channels allow display of an airplane symbol, a horizon, and a steering dot or circle plus four spare channels. Two rotation circuits are provided to allow two different sets of symbols to be rotated by independent inputs either in parallel or in series. To change from a moving-airplane display to a standard display, for example, requires only that one prepatched board be substituted for another. The symbol generator also has provision for the insertion of noise into any number of channels.

The position and rotation information for the symbol generator comes from a small Pace TR-20 analog computer. The computer is programmed to do wave shaping and conditioning as well as scaling and summing of the signals from the sensors and programmable task generators.

The sensor outputs are conditioned by appropriate interface circuits to make them acceptable to the analog computer. The removable patchboard on the computer allows experimental conditions to be changed in the same manner as display formats can be changed on the symbol generator, thus allowing further versatility.

Error along both the vertical and horizontal axes will be recorded on an Ampex SP-700 FM magnetic tape recorder. This approach allows the data to be analyzed directly from the magnetic tape with the use of a digital computer.

Aircraft

The aircraft in this flight research program is a Beechcraft C-45H. Rebuilt engines have been installed to maximize the probability of reliable operation. A new flight instrument panel, has been designed, fabricated, and installed (Figure 2). This instrument panel includes a Collins FD-109 flight director system on the left side to serve as a baseline control condition against which any improved display configuration employing the frequency-separation principle will ultimately be compared.

Experimental Planning

Preliminary determinations of the experimental variables, flight tasks, subject sample types and sizes, and performance measures have been made and

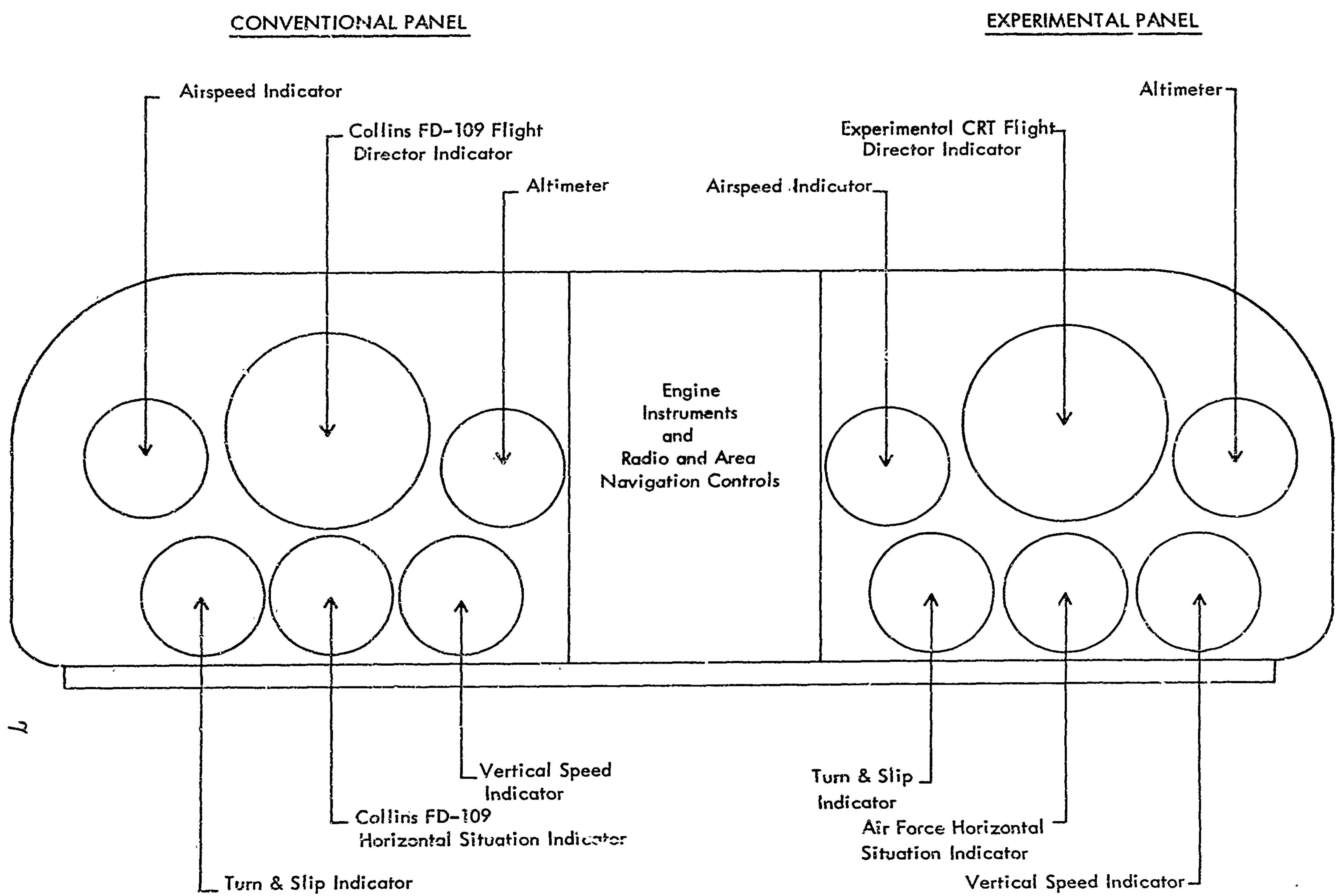

Figure 2. A comparison of conventional and experimental display panels.

were reviewed on 12 May, 1969, at the University of Illinois Aviation Research Laboratory by Dr. Marshall Farr, former project technical monitor from the ONR Engineering Psychology Branch, and by Dr. Morton Bertin, psychological research representative from the ONR office in Chicago.

SUMMARY OF PHASE II PROGRESS

The effective dates under which the second phase of the program was in progress were 1 April 1970 to 31 October 1970. During that period major areas of endeavor were final equipment optimization, installation and checkout of all equipment in the Beechcraft C-45H, FAA certification of the aircraft in its experimental configuration, and planning the formal experiments. During Phase II a review of the motion relationship problem in presenting aircraft attitude and guidance information was completed and submitted as a technical report. A copy of this study is incorporated herein by reference (Johnson and Roscoe, 1970a). A brief paper based upon this study and presented at the 14th Annual Meeting of the Human Factors Society in San Francisco on October 15, 1970, is also incorporated by reference (Johnson and Roscoe, 1970b).

Analog Computer Programming

The experimental apparatus constructed by Hughes Aircraft Company, including the task and symbol generators and CRT circuits, was interfaced with an EAI-31R analog computer at the Electrical Engineering Department of the University of Illinois. The use of this computer simulation of aircraft flight characteristics made it possible to do preliminary optimization of the experimental displays. Due to frequent malfunctions of the EAI-31R computer, however, the equipment was shifted to the Aviation Research Laboratory where it was interfaced with the Institute's Singer-Link GAT-2. There, equipment optimization was continued. This optimization was concerned with determination of the signals or combinations of signals to be used in the formal experiments for each experimental display. Signal shaping, conditioning, and scaling were accomplished during this optimization.

Sensors and Racks

The racks to hold the experimental apparatus have been constructed and installed in the test aircraft. The sensors, an Ampex SP 700 tape data recorder, a TR-20 analog computer, and a Brush 220 strip chart recorder have also been installed. The following sensors have been received from Naval Air Training Center, Naval Air Station, Maryland, and have been installed in the test aircraft:

1. Angle-of-Attack Position Transmitter
2. Vertical Gyro Transformer
3. Pressure Transducer
4. Rate Gyro
5. Free Gyro
6. Linear Potentiometer

The flight sensor instrumentation includes the following items received from Flight Control Division, Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio:

1. flight director computer
2. MD-1 GYRO
3. radio altimeter
4. angle-of-attack indicator

Aircraft Checkout and Certification

The aircraft in which the experimental apparatus has been installed has been inspected and flight tested by local representatives of the FAA Flight Standards Service and has been granted a Normal Category Airworthiness Certificate.

Experiment Planning

To accommodate the possibility of independent increments of funding being provided by the Office of Naval Research and by either the Air Force Flight Dynamics Laboratory or the JANAIR Program, our experiment plan has been divided into two parts. Sub-phase IIIA and sub-phase IIIB. Sub-phase IIIA, which has been funded by the Office of Naval Research, will consist of flight experiments using private pilots. The subjects will be tested with respect to original learning and transfer of learning through the use of the various display conditions. One possible experimental design might look like this:

Design	Number of Subjects	Learning	Transfer
1	5	A	A
2	5	A	B
3	5	A	C
4	5	B	B
5	5	B	A
6	5	B	C
7	5	C	C
8	5	C	A
9	5	C	B

Conditions 1, 4, and 7 are control conditions to evaluate the learning effect. Each pilot will be given a period at the beginning of the test to familiarize himself with the aircraft. The experimental task will be a complex tracking task, such as would be encountered in an air to air attack. Performance measures will consist primarily of root mean square errors and reversal errors.

Sub-phase IIIB would consist of using Naval Aviators at Miramar Naval Air Station and/or El Toro Marine Base to conduct an investigation using a simplified version of the previously cited experimental design.

Overlapping portions of Phase II and Phase IIIA are a parallel experimental effort employing the same equipment that has been funded by the Air Force Office of Scientific Research. This program involves experimental display comparisons during the landing phase of an IFR flight mission. Graduate

Research Assistants Joe A. Lamb and David C. Denney and Research Associate Richard J. Vanderkolk are currently conducting this complementary study.

Work to be Accomplished in Phase IIIA: Flight Experiments with Private Pilots.

The Aviation Research Laboratory of the Institute of Aviation, University of Illinois, will provide the necessary personnel, facilities, and equipment to accomplish Sub-phase IIIA of the Evaluation of the Frequency Separated Display Principle. This sub-phase consists of the following tasks: (Figure 3)

(1) Plan formal experiments for flight tests.
(2) Conduct flight experiments with private pilots.
(3) Conduct data analysis.
(4) Submit draft of final report for review and approval within 30 days.
(5) Publish approved version of report.

Statement of Work, Sub-phase IIIB: Aircraft Flight Experiments with Naval Aviators.

The Aviation Research Laboratory of the Institute of Aviation, University of Illinois, will provide the necessary personnel, facilities, and equipment to accomplish Sub-phase IIIB of the Evaluation of the Frequency Separated Display Principle. This sub-phase will consist of: (Figure 4)

(1) Plan formal experiments for flight tests.
(2) Conduct flight experiments with Naval Aviators.
(3) Conduct data analysis.
(4) Submit draft of final report for review and approval within 30 days.
(5) Publish approved version of report.

Organization and Personnel

The program will be performed by the Aviation Research Laboratory of the Institute of Aviation, University of Illinois. The Institute of Aviation is directed by Mr. Ralph E. Flexman, who reports to Dr. J. W. Peltason, Chancellor of the Urbana Champaign Campus of the University.

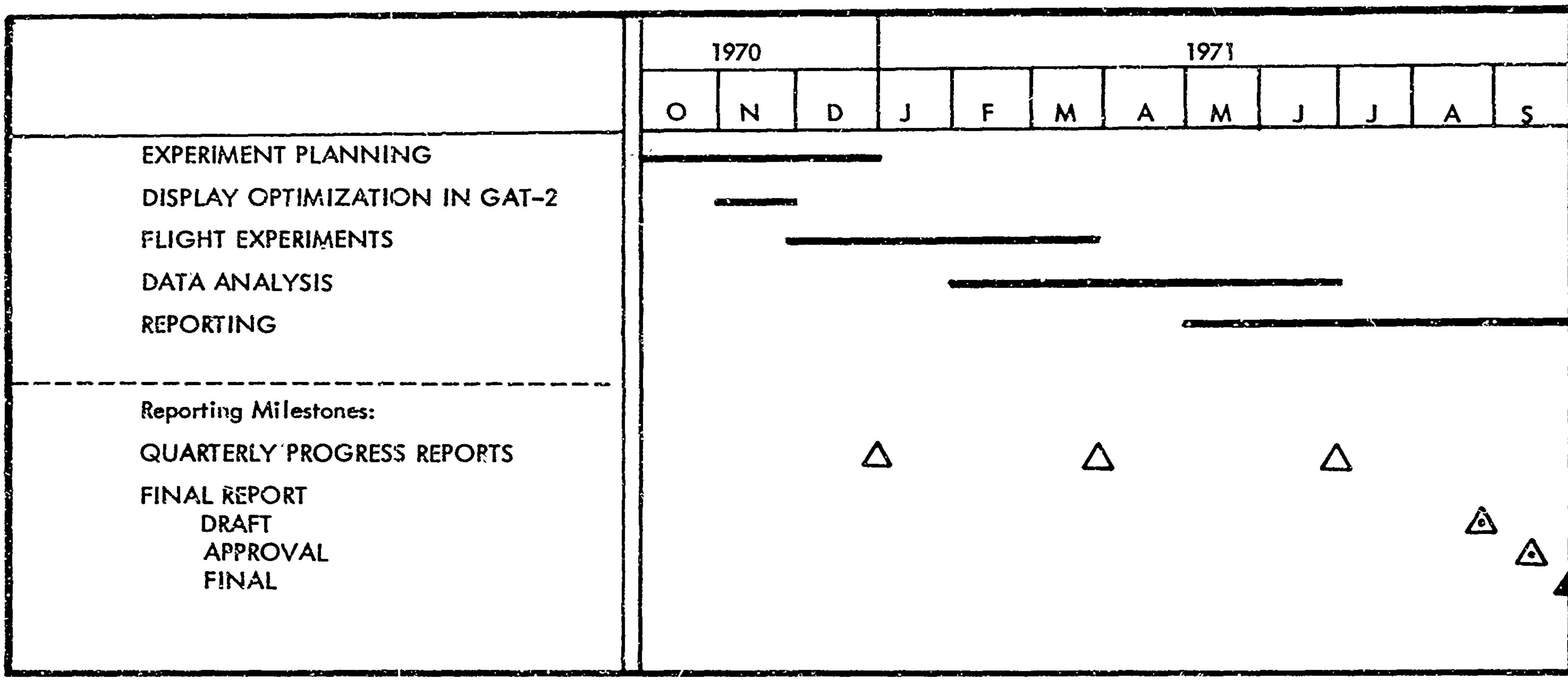

Figure 3. Schedule for Sub-Phase IIIA.

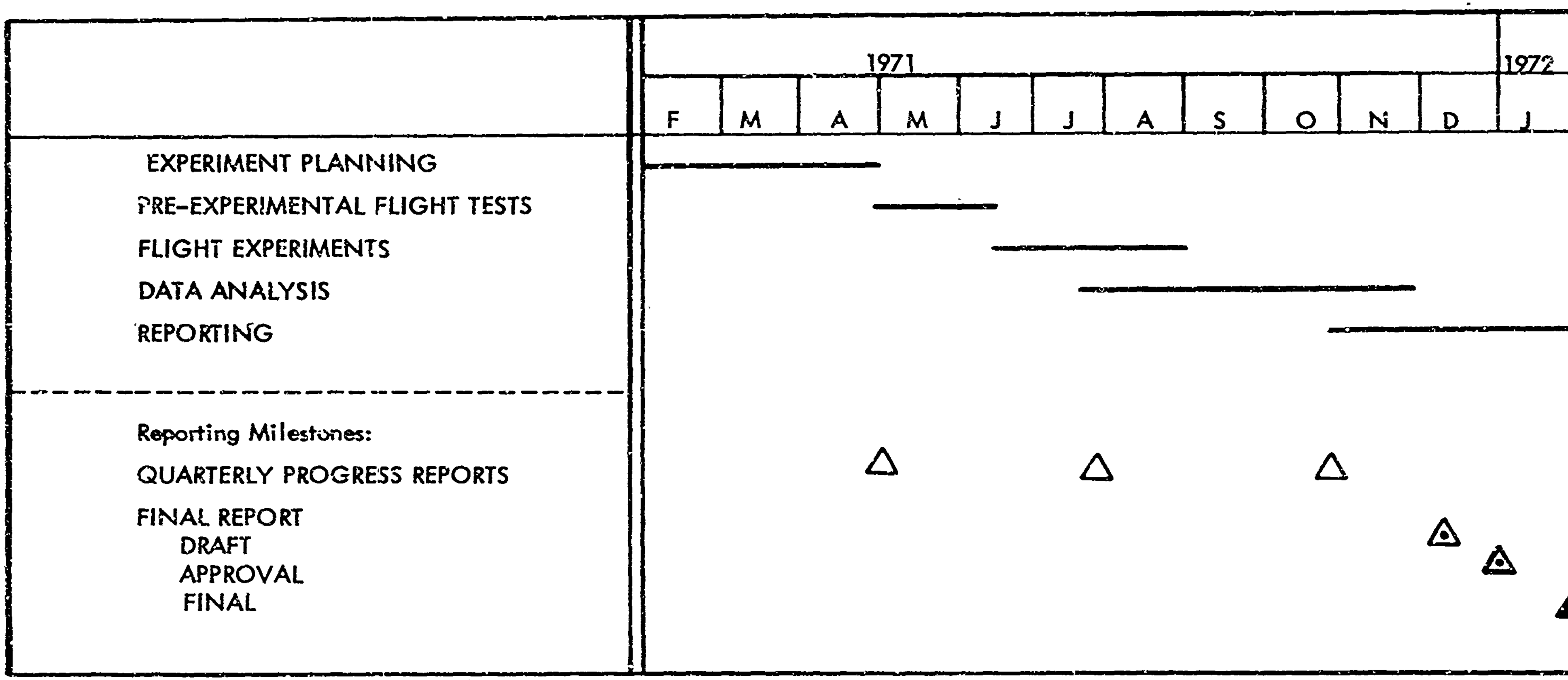

Figure 4. Schedule for Proposed Sub-Phase IIIB.

The principal investigator will continue to be Dr. Stanley N. Roscoe, Associate Director for Research of the Institute of Aviation and Head of the Aviation Research Laboratory. Graduate Research Assistant Steven L. Johnson, who is currently engaged in research on Phase II, will continue during Phase III. H. Kingsley Povenmire, who is also currently engaged on Phase II, will continue to be the project pilot.

With the funding of Sub-phase IIIB, two half-time Graduate Research Assistants will be hired. One Graduate Research Assistant, Joe Lamb, who is in aeronautical engineering, will be employed for twelve months, and one new assistant for three months. In addition, one additional Research Associate in the field of engineering will be hired.

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b. Johnson, S. L. and Roscoe, S. N. Frequency Separated flight displays. Savoy, Ill.: University of Illinois, Aviation Research Laboratory, Technical Report ONR-70-2, October 1970.

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